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A preliminary risk assessment of the potential for groundwater flooding during the winter of 2007/8 – an update

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Executive Summary

The unprecedented summer floods that took place in England during June and July 2007 raised concerns about the prospects for flooding, both fluvial and groundwater, over the coming winter. Floods occur when exceptional rainfall occurs over areas where antecedent conditions are favourable. While the processes controlling fluvial flooding can operate over a comparatively short period, ca. days, for groundwater floods the slow movement of groundwater means that antecedent conditions are established over a longer period, ca. months. Therefore, while caution needs to be exercised regarding the potential for fluvial flooding this coming winter but it is possible to begin to consider the situation for groundwater flooding, where the prerequisites are dominantly the depth to the water table and the water content of the overlying soils.

Groundwater flooding is defined, in this report, as flooding that can be attributed to water originating beneath the ground surface from permeable strata through a natural process. The aim of this study is to determine the extent to which the exceptionally heavy rainfall in the first half of the summer of 2007, and the conditions in the second half, have affected the likelihood of groundwater-related and other flooding occurring, in parts of England and Wales, during winter 2007/08. It is an initial risk assessment, i.e. Tier 1 – a qualitative screening process

The objectives are to:

- assess the situation of soil water and groundwater at the end of September for England and Wales using real data;
- make a preliminary assessment of possible trajectories of ground water levels, soil moistures and river flows (where baseflow is dominant) for the coming 4-6 months
- should significant risks of flooding be identified make recommendations for further detailed risk assessments (Tier 2 and 3).

Much of the knowledge about the occurrence of groundwater flooding is based on the winter of 2000/01, although data are available for more localised flooding that occurred in the winters of 1993/94, 1994/95 and 2002/03. Few incidences of groundwater flooding have been recorded for non-Chalk aquifers and so this report focuses on the outcrop of the Chalk aquifer.

The Chalk is particularly vulnerable to groundwater flooding due to the complexity of its hydraulic properties. These include: dual permeability through the matrix and fractures; low storage, low ability for water to flow in the saturated zone; significant variability in the hydraulic properties vertically and spatially. Even within the outcrop of the Chalk there is variability in the number of reported incidences of groundwater flooding so that the Chalk in Yorkshire and Lincolnshire has a low incidence of events compared to the Chalk to the south.

In the summer of 2007, there were several very wet periods, resulting in unprecedented May-July rainfall totals across much of southern Britain. The heavy storms in June and July even resulted in significant potential recharge occurring in many areas. Groundwater levels responded to this recharge so that, in the Cotswolds and parts of the Chalk in Yorkshire and Lincolnshire, previous summer groundwater levels were exceeded. In the southern outcrop of the Chalk, the response in the water table was more subdued but rises were observed at a number of sites. Complementary evidence is provided by the increased flow in streams and rivers sustained primarily by outflows from springs and rivers.

Remarkably, late July soil moisture deficits were lower than the average for the end of November across many aquifer outcrop areas. This extreme departure from the typical seasonal pattern implied that, in the absence of a very dry autumn, the 2007/08 recharge season might have extended for more than twice the normal duration in much of the English Lowlands. In reality the early autumn was notably dry, and this allowed the re-establishment of relatively normal seasonal soil moisture deficits by the end of September.

An initial assessment of the likelihood of groundwater flooding occurring over the winter of 2007/08 was made in August; based on the status and past behaviour of groundwater level observation wells in selected areas of the chalk outcrop. It provided an indication of the level of risk which suggested that high groundwater levels in the Chalk of Yorkshire and Lincolnshire and in the Berkshire and Chiltern Chalk might occur even with average winter rainfall. Significant flood events would be possible in most other areas if winter rainfall was high, although in the Southern Wessex Chalk the risk was lower.

By mid-October uncertainties about the impact of the exceptional summer recharge had been largely resolved and a clearer picture was emerging of the likely effect of the dry late summer and early autumn on the onset of the 2007/08 winter recharge season. This evidence suggests that the prospect of very high groundwater levels in the Chalk, and associated groundwater flooding, has significantly diminished over the last three months. In particular, groundwater level recessions in Yorkshire and Lincolnshire have been substantial since the late summer. Nevertheless the required antecedent conditions for flooding remain across much of the Chalk outcrop. Were there to be exceptional winter rainfall, some groundwater flooding is likely to occur but with average winter rainfall the areas at possible risk are likely to be confined to the Berkshire Chalk (extending into the Chilterns) and parts of the East Anglian Chalk. This risk will increase if a high proportion of the winter rainfall is concentrated in a relatively short timespan (4-6 weeks).

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Introduction

The unprecedented floods that took place in England during July 2007 have raised concerns about the prospects for flooding over the coming winter. Floods are essentially caused by exceptional rainfall but a series of antecedent conditions are generally prerequisites. These occur over a comparatively short period, ca. days, for fluvial floods but over a longer period, ca. months, for groundwater flooding. Therefore, caution needs to be exercised regarding the potential for fluvial flooding this coming winter but it is possible to consider the situation for groundwater flooding, where the prerequisites are dominantly the depth to the water table and the water content of the overlying soils.

Groundwater flooding is defined, in this report, as flooding that can be attributed to water originating beneath the ground surface from permeable strata through a natural process. Groundwater flooding can also occur in other hydrogeological settings, for instance in river valleys where permeable superficial deposits are in hydraulic contact with surface water, and flooding can occur as water moves from rivers into adjacent superficial deposits but these will only be touched on in passing.

The aim of this study is to determine the extent to which the exceptionally heavy rainfall in the first half of the summer of 2007, and the conditions in the second half, have affected the likelihood of groundwater-related flooding, and other flooding, occurring during winter 07/08, in parts of England and Wales. It is an initial risk assessment, i.e. Tier 1 – a qualitative screening process

The objectives are to:

- assess the situation of soil water and groundwater at the end of September for England and Wales using real data;
- make a preliminary assessment of possible trajectories of ground water levels, soil moistures and river flows (where baseflow is dominant) for the coming 4-6 months
- make recommendations for further detailed risk assessments (Tier 2 and 3) of any potential for groundwater flooding this coming winter, including the optimum timing of these.

This report is an update of an earlier one, August 2007, in which, although predictions were made, there was still significant uncertainty about the likelihood of groundwater flooding in the coming winter as late summer and autumn rainfall were unknown and because of delayed groundwater responses due to the slow passage of infiltration through the unsaturated zone. We now know what the rainfall was in this period, generally below average, and have more data on groundwater responses and so can comment with greater confidence.

The occurrence of groundwater flooding

There is an appreciable amount of, mostly local and qualitative, evidence of historical groundwater flooding (British Hydrological Society - Chronology of British Hydrological Events) in the UK but, prior to the winter of 2000/01, groundwater flooding had received relatively little formal attention from either academic or regulatory communities, because the events that had occurred in the previous few decades were localised. The 2000/01 event is probably the best formally documented event, although data are available for more localised flooding that occurred in the winters of 1993/94, 1994/95 and 2002/03. The 2000/01 flooding was largely due to the exceptional rainfall in the period between September 2000 and April

2001, the wettest 8-month sequence in the 241-year England and Wales rainfall series (Marsh and Dale, 2002); the rainfall anomalies were most outstanding across southern England. The steep recovery of groundwater levels, following the summer recession, began from levels that were at or a little above the seasonal mean. Water-table rises gathered momentum from mid-October and, during the late autumn the rates of rise were remarkable. In many areas the groundwater levels exceeded the previous maxima for several months. From early December, water tables began to reach the ground surface in many aquifer outcrop areas and groundwater flooding persisted for more than four months in some places. The meteorological conditions that led to the 2000/01 floods were focussed on southern Britain, with the greatest impacts on the Chilterns, the Berkshire and Wessex Chalk, and on the Chalk of the South Downs. Jacobs (2004) collated data on the incidence of groundwater flooding during the three winters of 1994/95, 2000/01 and 2002/03. They concluded that groundwater flooding appeared to be largely restricted to the outcrop of the Chalk where there are no overlying impermeable deposits. Subsequently, Jacobs (2006a, b) extended this analysis, confirming this conclusion.

There is very little information on the occurrence of groundwater flooding in non-Chalk aquifers. Jacobs (2006a) attributed the low incidence of groundwater flooding outside the Chalk aquifers to one or more of:

- Relatively high storage values;
- Lower permeability formations having a slow rate of recharge;
- High permeability formations rapidly dissipate any elevated heads.

It is possible that groundwater flooding occurs more widely in these geological formations, but has not been formally recorded.

Given the widespread and extreme nature of the 2000/01 flooding and the low incidence of groundwater flooding that resulted in non-Chalk aquifers, the current analysis focuses on the Chalk.

The complexity of its hydraulic properties make the Chalk particularly vulnerable to groundwater flooding. The Chalk is considered to be a dual permeability system as flow occurs both through the pores of the matrix and through fractures distributed throughout the rock mass. Both the pores and the fractures have a low storage in the unsaturated zone. Thus recharge to the saturated zone results in comparatively large rises in the groundwater levels. Although the movement of water downwards in the unsaturated zone is dominantly through the matrix (Mathias *et al.*, 2006, Ireson *et al.*, 2006), and thus slow, the response of the water table occurs on a much shorter timescale due to the hydraulic pressure transmitted through the water in the matrix, which is close to saturation. In addition, a more rapid response can occur due to flow through the fractures when the water table is close (ca less than 5 m) to the ground surface. In the saturated zone, the flow of water is almost exclusively through the fracture system and so there is a relatively low ability for water to travel laterally through the system - thus elevated groundwater levels can take months to dissipate, increasing the impact of any flood. In addition, the hydraulic properties vary vertically (e.g. Rushton *et al.* 1989, Bradford 2002, Williams *et al.*, 2006) which can result in a non-linear response of groundwater levels. A further level of complexity is that the hydraulic properties vary spatially. Controls on the distribution of permeability and storage include lithology, structure and the effect of Palaeogene cover. Topography and periglacial processes can serve to enhance solution along fractures and hence permeability (Allen *et al.*, 1997). This spatial heterogeneity explains much of the local variations in the occurrence of groundwater flooding recorded by Jacobs (2004). For instance the relatively high transmissivity of Chalk at outcrop

in Lincolnshire and Yorkshire may allow faster drainage and thus the rapid attenuation of elevated groundwater levels, reducing the instances of flooding.

The areas most at risk from groundwater flooding in Southern England can be localised further. Jacobs (2004) identify that the Environment Agency Areas with the most reported occurrence of groundwater flooding from major aquifers are: Anglian – central; Southern – Hampshire & Isle of Wight; Thames – West and North East.

While the areas within Southern England affected by flooding in 2000/01 are considered to be most at risk from future groundwater flooding, other areas of the Chalk, and other aquifers that might be susceptible to localised groundwater flooding can be identified from detailed geological mapping and groundwater level datasets. The lack of observational evidence from previous flooding episodes means that predicting the risk of future events in these areas is impractical.

Groundwater conditions in the summer and early autumn of 2007

Antecedent groundwater conditions

Following protracted drought conditions extending over two years, the seasonal recovery in groundwater levels in 2006 began from a very low base. Generally, the 2006/07 recharge season was initiated in the early autumn and the third wettest October-February period for England and Wales since 1960/61 ensured that groundwater levels in most major aquifer outcrops were above the seasonal average by early spring 2007. There were exceptions, including the very slow-responding Permo-Triassic sandstones of the Midlands. Modest March rainfall and a remarkably dry and warm April then triggered an early and relatively steep onset of the 2007 seasonal recession in groundwater levels.

Rainfall

Synoptic patterns changed in early May – the strength, and southerly track, of the Jet Stream, together with elevated sea surface temperatures, contributed to a continuation of very unsettled, cyclonic weather conditions over the May-July period, especially across England and Wales. For this area, the three-month rainfall total eclipsed the previous May-July maximum (in a series from 1766) by an appreciable margin. Many wetter 3-month periods can be found but none since 1912 fall in the summer half-year (May-Sept). Across the majority of the major aquifer outcrop areas, the late May-July rainfall was more than twice the 1961-90 average, rising to over 300% in parts of the Cotswolds (Jurassic Limestone) and the Yorkshire and Lincolnshire Wolds (Chalk) – see Figure 1. Importantly however, rainfall anomalies were less outstanding across the South East (i.e. much of the area most vulnerable to groundwater flooding).

Within the May-July period there were several extremely wet episodes which generated substantial, and rare, summer recharge. The June rainfall total for Yorkshire was the highest for any month in a series from 1914 and exceptional storm totals were reported on the 15/16th and 24/25th – when Winestead (near Hull) recorded 100 mm in 12 hours. In July, a sub-tropical air mass stagnated over central England generating extreme rainfall totals: Pershore (Hereford and Worcestershire) recorded 145 mm in 25 hrs on the 19/20th (return period > 1000 yrs) with an area of around 3500 km² registering >100 mm (see Figure 2).

Late July saw the end of the exceptional cyclonicity which produced the outstanding late spring and early summer rainfall across much of southern Britain. Frontal systems were much less frequent in the late summer and early autumn and, from around the 20th August, a notable dry spell developed which had extended beyond 30 days by mid-September. Some areas (e.g. in the Lower Severn basin) registered no measurable rainfall during this episode, and much of central England reported <5 mm. Following a wet interlude in mid-September, relatively dry conditions then continued into early October.

The notable contrast between the May-July rainfall and that for the succeeding two months is evident when Figures 1 and 3 are compared. The wettest May-July in the 241-year England & Wales rainfall series was succeeded by the 3rd driest Aug/Sept since 1991. More notably in relation to winter flood risk, particularly modest late summer and early autumn rainfall was reported for those areas worst afflicted by the summer flooding. Over September and October, large parts of Yorkshire, the west Midlands and the lower Severn basin reported less than half the average rainfall. Provisional data indicate that, for some catchments (e.g. in Lincolnshire), the Aug/Sept rainfall was the 3rd lowest in over 40 years. Rainfall was also very meagre over much of the Jurassic Limestone outcrop and some Permo-Triassic sandstones outcrops in the Midlands. The two-month anomalies were less notable across the Chalk but many outcrops received less than 65% of the average rainfall. The rainfall for the first half of October was generally below average with the exception of a band extending from the Berkshire Downs to East Anglia within which the rainfall was around average.

Soil moisture

The unprecedented May-July rainfall across much of southern Britain produced hydrological conditions with no close modern parallel for the summer (June-August). An important measure of the singular nature of the 2007 summer is provided by the outstandingly wet soil conditions. At the end of June, MORECS¹ soil moisture deficits – averaged across England and Wales – were the lowest on record (in a series from 1961). End-of-July totals were similarly outstanding; substantially below the previous minimum for England and Wales. The exceptional wetness of the summer soils is illustrated in Figure 4 which shows (for the Berkshire Downs) that the low soil moisture deficits during July were without precedent in the previous 35 years. In a normal year, late-July soil moisture deficits are in the range of 90-110 mm across the major outcrop areas in the English Lowlands; deficits in 2007 were less than 30 mm over a very wide area (see Figure 5).

Thereafter however evaporation demands, though declining, generally exceeded rainfall totals and soil moisture deficits began a much belated seasonal increase through August. Soils continued to dry out in September and by early October, soil moisture deficits had returned to the normal range across most of England & Wales (see Figure 6). Spatial variations in soil moisture deficits were, however, significant (see Figure 7): soils remained wetter than normal in parts of the eastern Chalk (e.g. in Norfolk and Kent) whilst soil moisture deficits exceeded the average in parts of the southern Cotswolds and parts of the Magnesian Limestone outcrop.

The brisk decline in soil moisture deficits through the early autumn substantially moderated the risk of flooding and allowed groundwater level recessions to become firmly re-established. By mid-October, soil moisture deficits were the equivalent of 5-8 weeks autumn

¹ MORECS: Met Office Rainfall and Evaporation Calculation System (Hough and Jones, 1998)

rainfall, indicating that the winter recovery in groundwater levels would, given normal rainfall patterns, commence in the late autumn or early winter – as is normally the case in the major aquifers.

The groundwater response

Dry soil conditions normally preclude widespread aquifer recharge during the summer. In 2007, the wet soil conditions resulted in the summer rainfall being very hydrologically effective in some areas. In parts of the Cotswolds, estimated infiltration in July exceeded the average for January (Anon. 2007). As a consequence, previous maximum summer groundwater levels were exceeded, by wide margins in some cases, e.g. at Ampney Crucis in the Jurassic Limestone of the Cotswolds. More notable was the unseasonably early recovery in the slower-responding Chalk of the Lincolnshire and Yorkshires Wolds (see Figure 8). In the latter, levels at Dalton Holme were the highest for the summer in a 120-year series. Exceptional summer responses also occurred in some western outcrops of the Chalk (e.g. at Rockley, Wiltshire). Generally, away from these – the wettest – outcrop areas, overall recharge through the summer remained modest, albeit often significant by comparison to the minimal recharge normally registered in the June-August timeframe.

Complementary evidence of the magnitude of the groundwater replenishment during the summer is provided by the 2007 river flow patterns in streams and rivers sustained primarily by outflows from springs and seepages. Figure 10 shows 2000-07 daily flow hydrographs for a number of index rivers in England. The July peaks on the Coln, which drains from Cotswolds, and the Lambourn (Berkshire Downs) exceeded previous maxima² and by month-end baseflows (the groundwater contribution) were well above those in any previous summer. By contrast, flows in the Chess (Chilterns) and the Mimram (draining the Chalk, north of London) remained well within the normal summer range during July.

The spatial variation in fluvial baseflow response to the summer rainfall is paralleled by groundwater levels; in much of the South East, the July 2007 groundwater levels followed a reasonably typical recession. July levels were also within the normal late-summer range in many Permo-Triassic sandstones outcrops.

The development of soil moisture deficits through August served to terminate an extraordinary summer recharge episode and soil moisture deficits continued to increase through September (contrary to the normal seasonal pattern). Early autumn soil moisture conditions thus exercised a normal seasonal constraint on aquifer recharge rates. Infiltration during the three months from early August was minimal across the outcrop areas of the major aquifers.

The associated cessation of recharge is clearly evident in the groundwater levels hydrographs for a number of responsive aquifers (see Figure 11). However, the scale and impact of the unique pulse of summer recharge in 2007 varies both spatially and temporally, reflecting differences in rainfall patterns, aquifer characteristics and depth to the water-table.

² Note: in both cases it is assumed that the rainfall on the 19/20th July exceeded the infiltration capacity of the soils and surface runoff was a significant contributor to the highest daily flow).

September groundwater levels were generally above average (see Figure 9); notably so in many outcrops of the Jurassic Limestone (where September levels were still rising at the confined New Red Lion well) and in the western and northern extremities of the Chalk. In the latter, despite recent recessions, new September maximum levels were established at Aylesby and Rockley (in a series from 1933). Levels were also seasonally very high at Wash Pit Farm in Norfolk. Levels were still increasing in many of the slow responding Permo-Triassic outcrops in the Midlands; a particularly brisk recovery has been registered at Nuttall's Farm since the early summer.

After registering outstanding summer and early autumn peaks, groundwater levels in most responsive aquifers, (e.g. the Carboniferous and Jurassic limestones) had returned to the normal range by mid-October. However, the full effect of the summer recharge has yet to register on the hydrographs for many slower-responding units of the Chalk and the Permo-Triassic sandstones of the Midlands. In the latter, notable increases in level were recorded in September – but depressed levels at the end of the 2004-06 drought meant that October levels were in the normal range.

Late October levels in Chalk index wells were generally below those recorded at the corresponding time in 2000, prior to the most extensive groundwater flooding of modern times (see page 1).

River flows

Despite the limited August rainfall, catchment runoff totals for the summer (June- August) of 2007 exceeded previous maxima for the majority of index rivers across the UK. For the Great Ouse and Warwickshire Avon previous maxima were eclipsed by considerable margins in records of >70 years. The extension in the range of recorded summer flows was particularly evident in some spring-fed rivers. In the Lincolnshire Chalk, runoff for the River Lud was more than twice the previous maximum in a 40-year series (see Figure 11). As remarkably, flows in the River Coln (draining the Jurassic Limestone of the Cotswolds) remained above previous daily maxima for three months until the end of September.

The hydrological impact of the limited late summer and early autumn rainfall was strongly influenced by catchment geology. Flows declined gently in most groundwater-fed rivers and streams. By contrast, recessions in rivers draining impermeable catchments were steep and sustained. After the exceptional July flooding, flows in the Severn declined to below the average for the third week of September.

September runoff totals were below average for most rivers draining impermeable catchments and, with recessions continuing, fluvial flood risk had diminished greatly by early October. The hydrological transformation was much less notable in many permeable catchments. September runoff totals were exceptionally high in many spring-fed streams and rivers – from Yorkshire to Dorset – with record monthly totals registered in some catchments (e.g. the Lambourn and Coln). In such catchments the winter recovery in runoff rates is likely to begin with flows appreciably above the seasonal average. Correspondingly, the risk of fluvial flooding will be enhanced, particularly in the event of a wet winter.

Historical perspective

Whilst very localised summer recharge, normally associated with convective storms, is not unusual, substantial and widespread aquifer recharge during the June-August period is very rare, particularly in the context of the last 100 years. Prior to the First World War summer half-year rainfall commonly exceeded that for the winter half-year (Nov-Apr) (Marsh et al, 2007) and summer infiltration was a more regular occurrence (e.g. in 1797, 1860, 1879 and 1912). Over the period during which a relatively dense borehole monitoring network has been maintained – the last 40 years – there is no summer recharge episode to compare with the hydrological conditions experienced in 2007. Correspondingly, there are few analogues on which to base scenarios for the behaviour of groundwater through the coming autumn and winter. Fortunately, results from the recent NERC Lowland Catchment Research (LOCAR) Programme have substantially added to our understanding of the hydrological processes in the near surface, unsaturated and saturated zones of the Chalk with the result that we are better placed both to interpret the observations of the recent events and to make predictions of the future.

The outlook

Remarkably, late July soil moisture deficits were lower than the average for the end of November across many aquifer outcrop areas, and at that time it appeared that even average rainfall from August to March could have translated into 150% of average recharge across much of the Chalk outcrop, with greater anomalies in some areas. However, the subsequent below average rainfall over much of the English Lowlands has resulted in soil moisture deficits developing so that, by early October, the soil moisture deficits were generally only a little below those that would be expected for that time of year. As a result, the normal seasonal increase in runoff and recharge rates is expected to start at about the normal time or later. Thus, the prospect for fluvial flooding is not significantly different to a “normal” winter (but see below).

It now seems less likely that a severe groundwater flooding event, e.g. on the scale of 2000-1, will occur. However, many late summer groundwater levels exceeded the seasonal average and thus there is an enhanced risk, should there be periods of intense rainfall over the winter. Similarly, there is an enhanced risk of fluvial flooding in rivers with a strong baseflow component. However, it should be noted that above average winter rainfall does not necessarily imply the occurrence of floods. For example, last winter (October-March) the rainfall in England and Wales was significantly above average, 115-130 %, and yet floods were noticeable for their absence. This was because there were no exceptional rainfall events.

An initial assessment of the likelihood of groundwater flooding occurring over the winter of 2007/08 has been made based on the status and past behaviour of groundwater level observation wells in selected areas of the Chalk outcrop. Three scenarios were examined.

- A. High winter rainfall (>150% of long term average Oct – Mar)
- B. Normal winter rainfall (100% of long term average Oct – Mar)
- C. Low winter rainfall (75% of long term average Oct – Mar)

The normality of rainfall over outcrop areas during October, and the forecast [Met Office’s forecast for November 2007 (see Box 1)] of a possibly drier than average November make the high winter rainfall scenario increasingly unlikely to be realised.

The historical data for the selected boreholes were then reviewed. The average water level rise over winters with rainfall matching the selected scenario was calculated and applied to a predicted 'end of recession' groundwater level. The resulting prediction was compared to the previous recorded maxima and to levels that are known to have produced groundwater flooding. Where levels equal historical maxima or flood levels the risk is assessed as possible, otherwise the risk of flooding is considered low. Where predicted levels either exceed historical maxima or groundwater flooding trigger levels the risk is assessed as appreciable. It should be noted that this is a change in the terminology from that used in the previous report and reflects the reduction in the likelihood of a major flooding event.

The precision of these analyses is very limited; there are no recent historical analogues for the intense June and July rains, so the precursors to historical floods will have been different. No account has been taken of rainfall intensity or its temporal distribution through the winter half-year. In some cases the predicted levels significantly exceed historically observed levels, but in reality non-linearity in borehole response to recharge and increases in spring discharge or baseflow are likely to limit the real rise in water table. A further source of uncertainty is that some recharge from the summer rains may not have reached the water table, leading to an underestimation of flood risk.

The results of the analysis are shown below:

| Area | Borehole | Rise A – High Rainfall | B- 100% Rainfall | C - 75% Rainfall |
|---|----------------|------------------------|------------------|------------------|
| Chance of exceptionally high groundwater levels | | | | |
| Yorkshire/Lincolnshire | Dalton Holme | 9.5 Possible | 8.3 Possible | 6.0 Low |
| | Aylsbey | 7.6 Possible | 7.3 Possible | 4.4 Low |
| Berkshire/Chilterns | Rockley | 14.2 | | |
| | | 12.2 Appreciable | 6.4 Possible | |
| Wessex | Compton | 35.4 Possible | 22.0 Low | 12.7 Low |
| South Downs/Kent | West Dean No 3 | 2.6 Appreciable | 1.2 Low | 0.9 Low |
| East Anglia | Washpit Farm | 6.4 Appreciable | 3.8 Possible | 1.6 Low |

There are several differences between this analysis and that produced in August. The relatively dry conditions have reduced the overall probability of flood events. Groundwater recessions in Yorkshire/Lincolnshire have been greater than expected, reducing water levels and hence the risk of a groundwater flooding event. In East Anglia, slow responding aquifers had reached record levels for September, so the possibility of a flooding event has been raised slightly.

With high rainfalls the areas that would be most likely to suffer from high groundwater levels would be the Berkshire Downs/Chilterns, the South Downs and East Anglia. There are good historical precedents for flooding occurring in the first two areas, but less evidence of significant flooding in the slower responding, and often drift covered, East Anglian aquifers. In other Chalk aquifers flooding under a high rainfall scenario may occur, but is likely to be localised.

October groundwater levels in many aquifers were still above average for the time of year. In relation to their levels in the autumn of previous years when flooding events occurred, even with average amounts of rainfall some flooding is possible in Berkshire/Chilterns, East Anglia and Yorkshire, Lincolnshire. The same provisos apply, in that, within these areas there is a known history of groundwater flooding in the Berkshire/Chilterns area, and some evidence that underlying geological conditions in Yorkshire, Lincolnshire and East Anglia make flooding less likely.

Outside the Chalk, some areas of the Jurassic limestones and Permo-Triassic sandstones have been subject to exceptional amounts of summer recharge. As discussed above, these aquifers are not considered to suffer groundwater flooding, but the possibility that flooding may occur, and that winter baseflows and spring discharges will be significantly higher than normal can not be dismissed.

Recommendations

The risk of groundwater flooding has diminished over much of the English Lowlands as a consequence of the below average rainfall during the late summer and autumn. Nevertheless, in some areas (Berkshire/Chilterns, East Anglia and Yorkshire, Lincolnshire) the risk is still appreciable and so it is recommended that these areas should remain a focus for monitoring of the groundwater situation, particularly if above average rainfall occurs in the late autumn/early winter.

The Chalk aquifer should be the main focus for any further risk assessments because the historic occurrence of groundwater flooding suggests that these events are most likely to occur here. However, there is the possibility of localised events on other major aquifers this winter and, if they occur, they should be monitored so as to add to our knowledge of this phenomenon.

The ongoing research project “Modelling groundwater flood risk in the Chalk aquifer from future extreme rainfall events”, under the NERC Flood Risk from Extreme Events (FREE) programme, is developing a conceptual understanding and a detailed numerical model of groundwater flooding in the Chalk aquifer. It will also investigate simpler methods of prediction, more suitable for operational use. Thus, there is the potential for the results of this research to be taken up to improve groundwater flood prediction.

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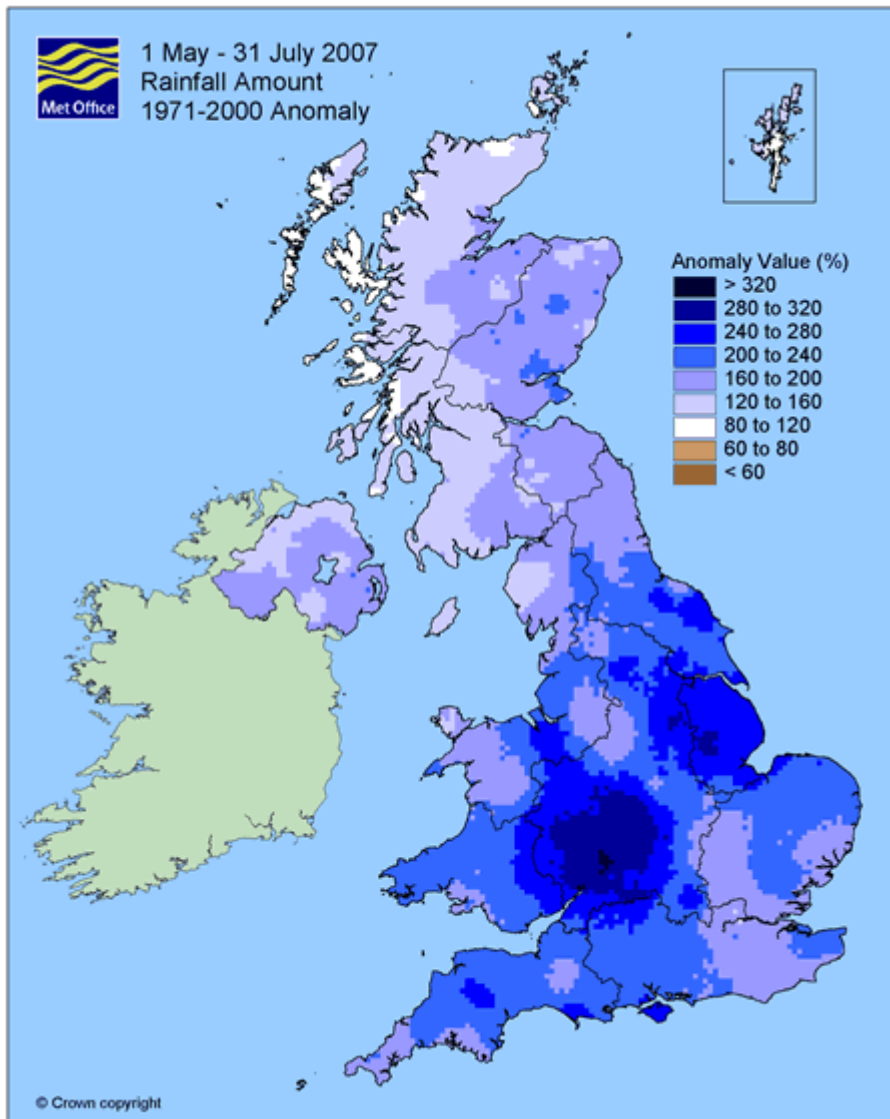


Figure 1 The rainfall anomaly (1971-2000) for 1 May – 31 July 2007 over the UK (reproduced courtesy of the Met. Office)

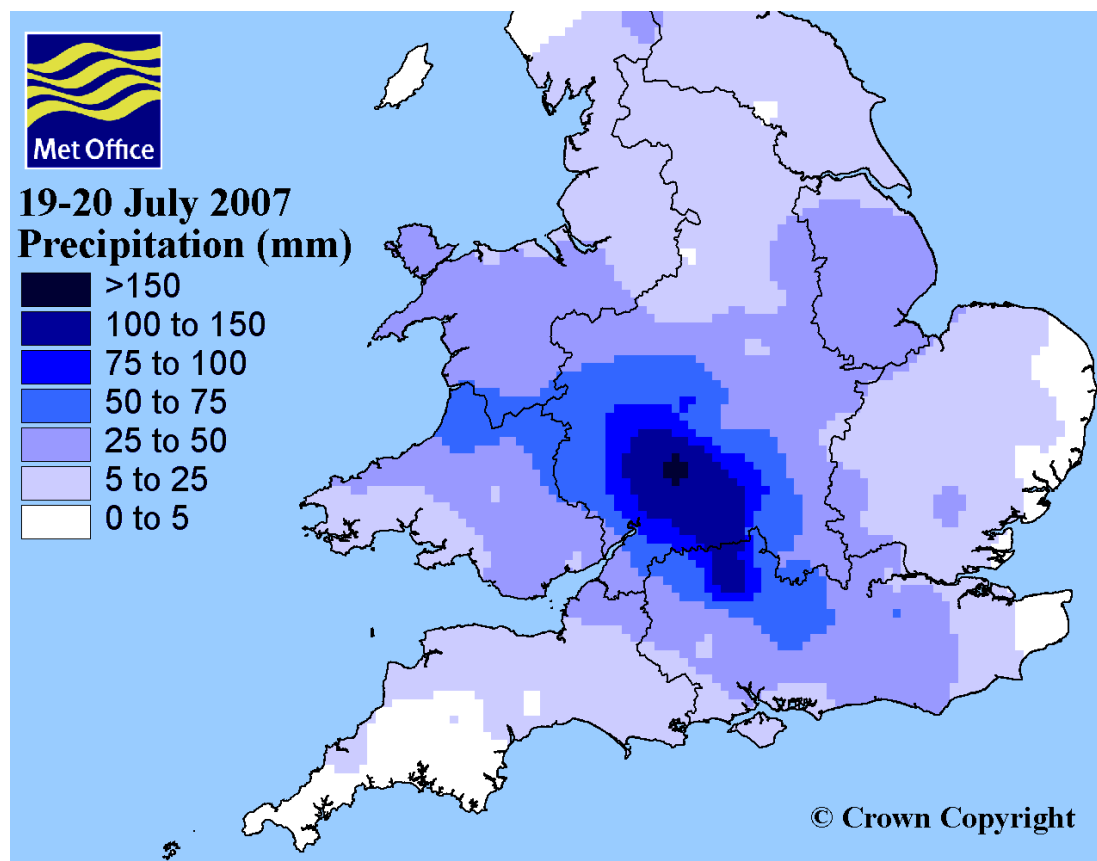


Figure 2 The total precipitation for the period 19-20 July 2007 (reproduced courtesy of the Met. Office)

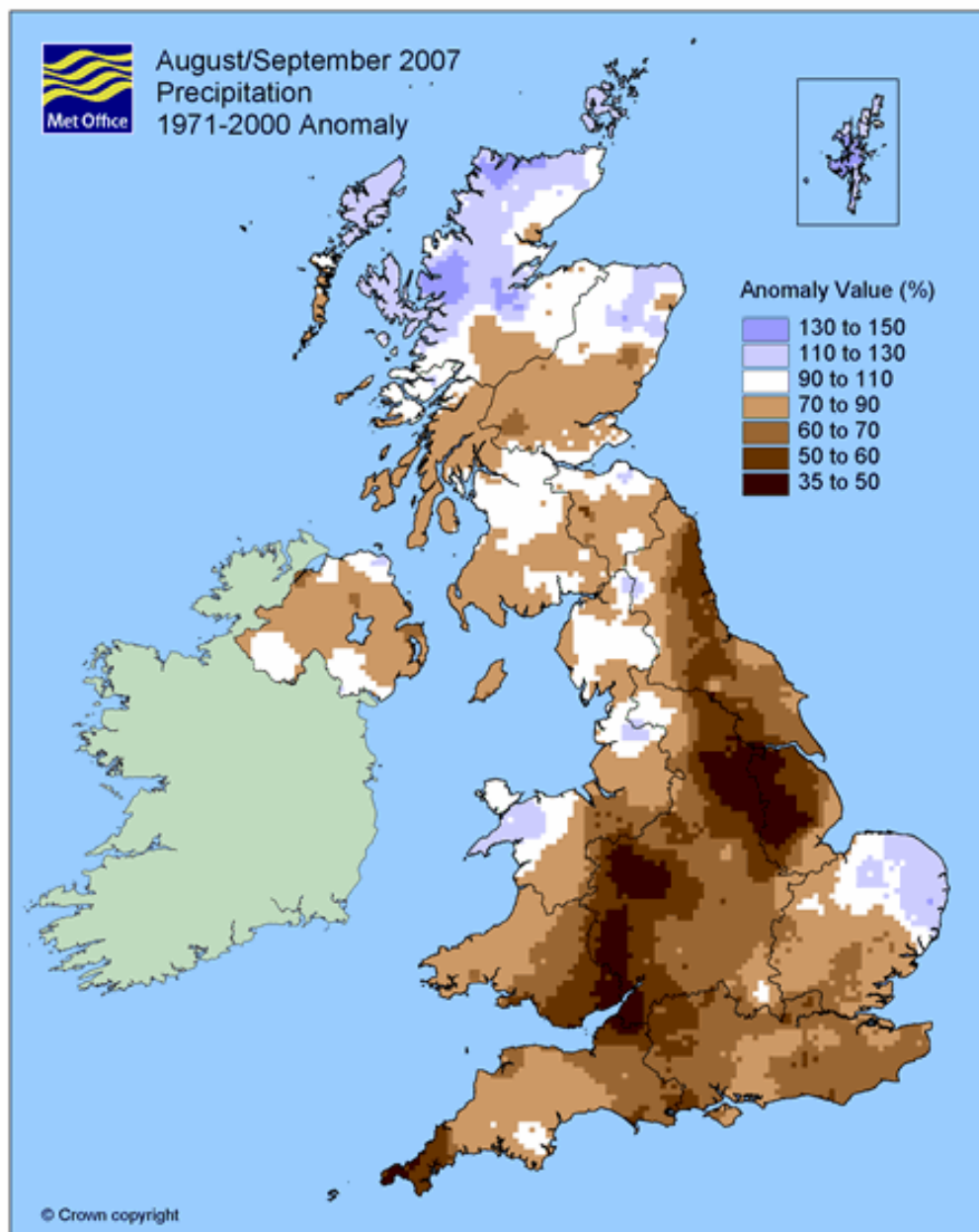


Figure 3 The rainfall anomaly (1971-2000) for August and September 2007 over the UK (reproduced courtesy of the Met. Office)

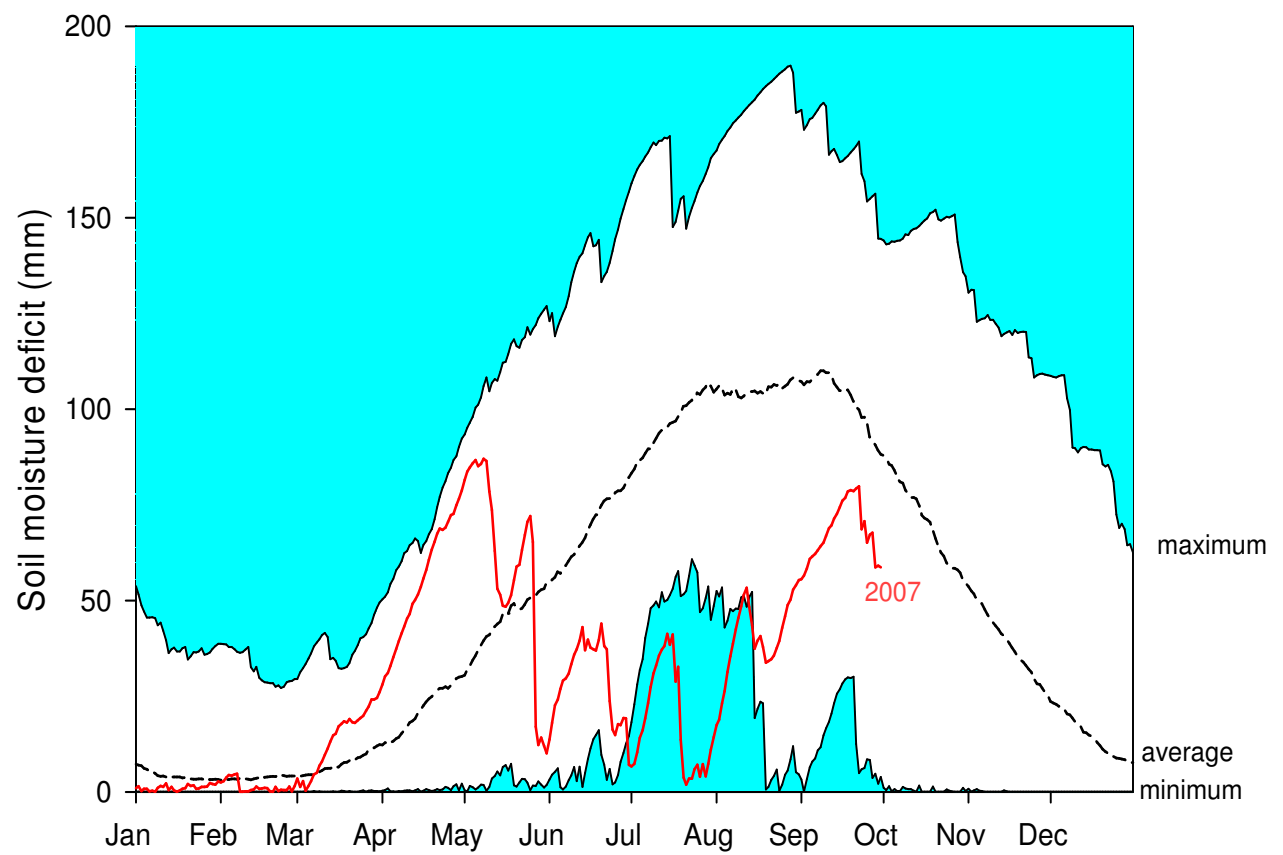


Figure 4 Simulated daily soil moisture deficits for 2007 at a site on the West Berkshire, Downs, compared to the minimum, maximum and average values of 1973-2006

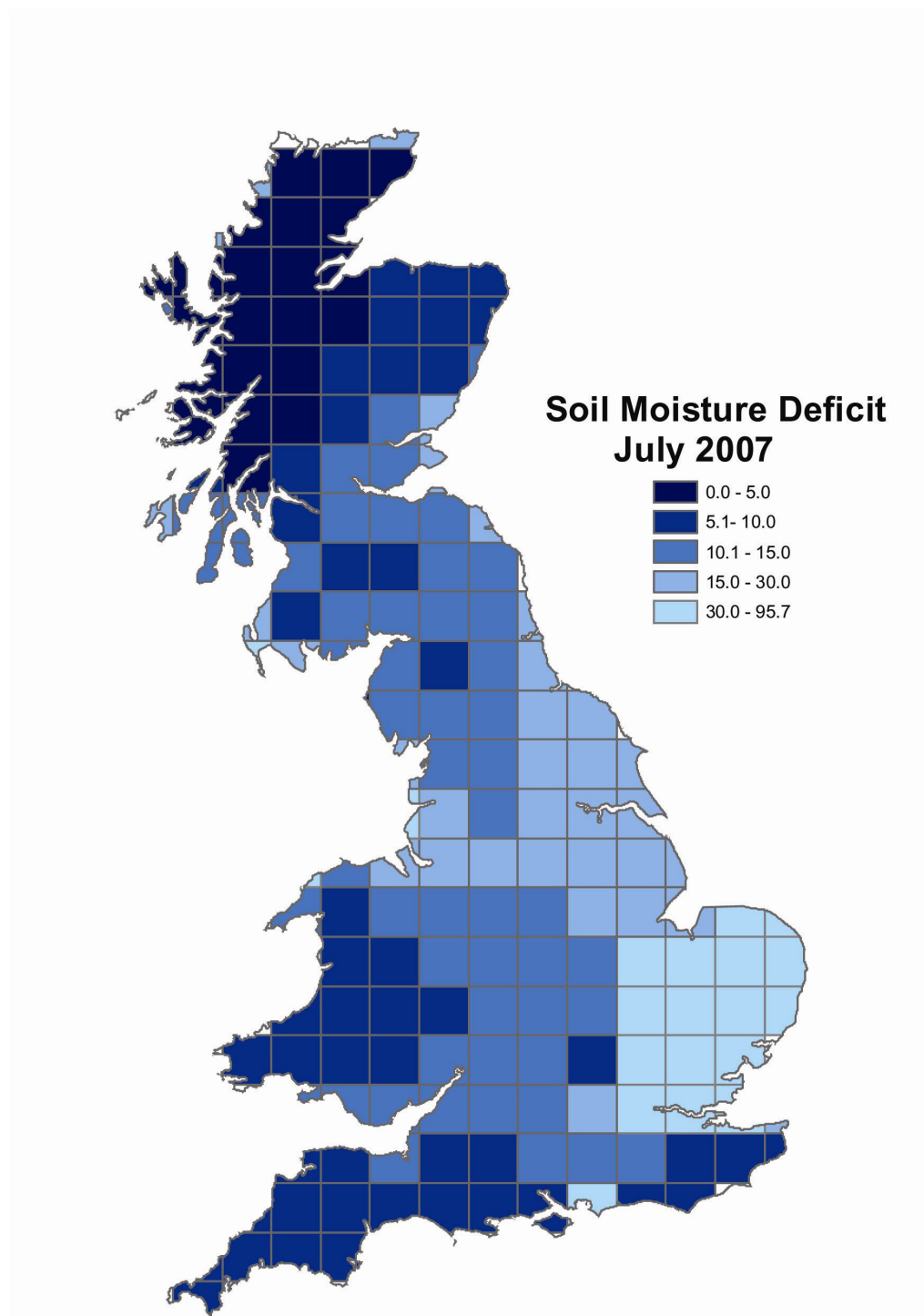


Figure 5 MORECS soil moisture deficits in late-July 2007

September 2007

SMD (mm)

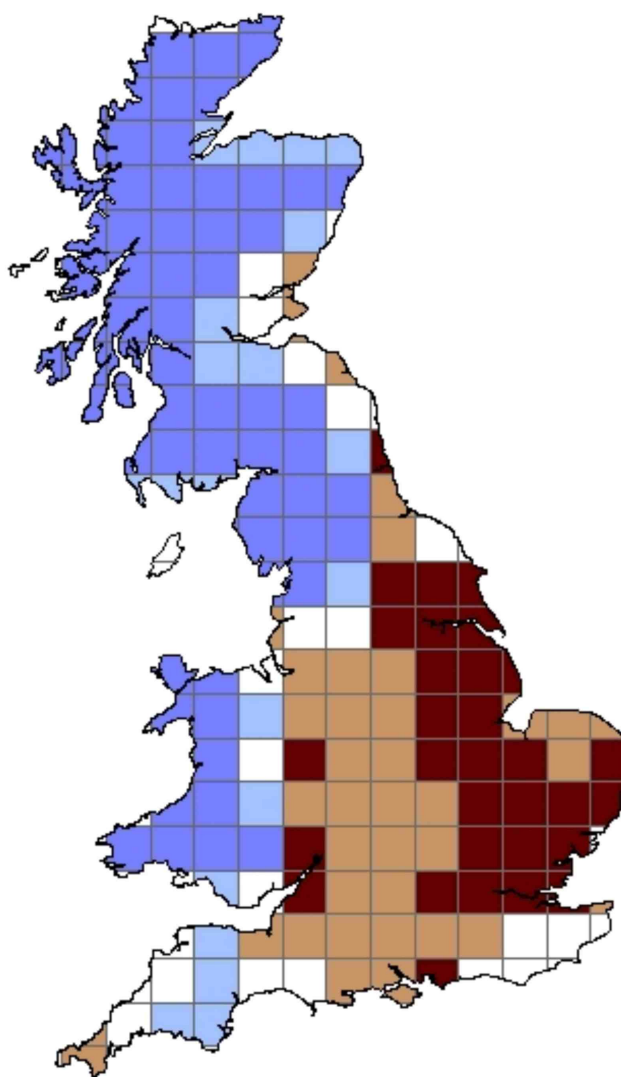
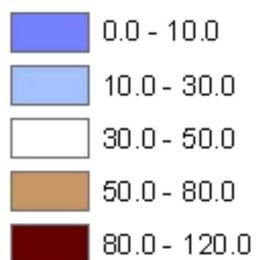


Figure 6 MORECS soil moisture deficits in late-September 2007

September 2007

Anomaly (mm)

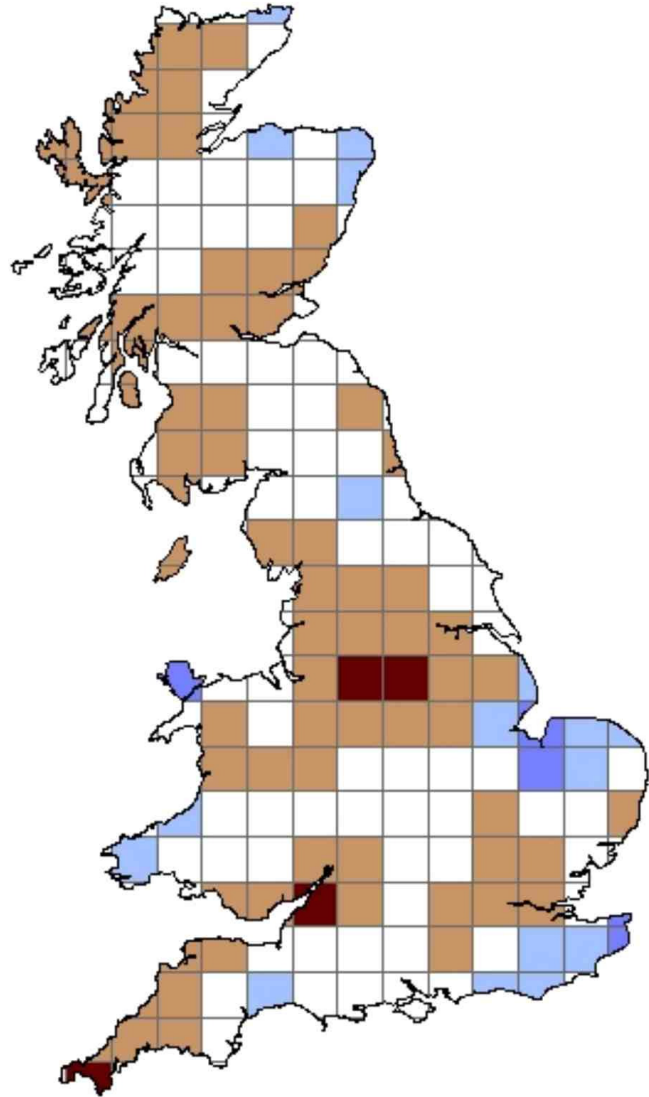
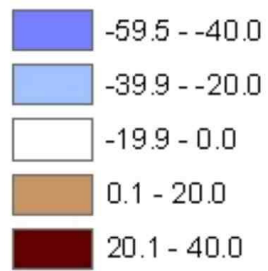
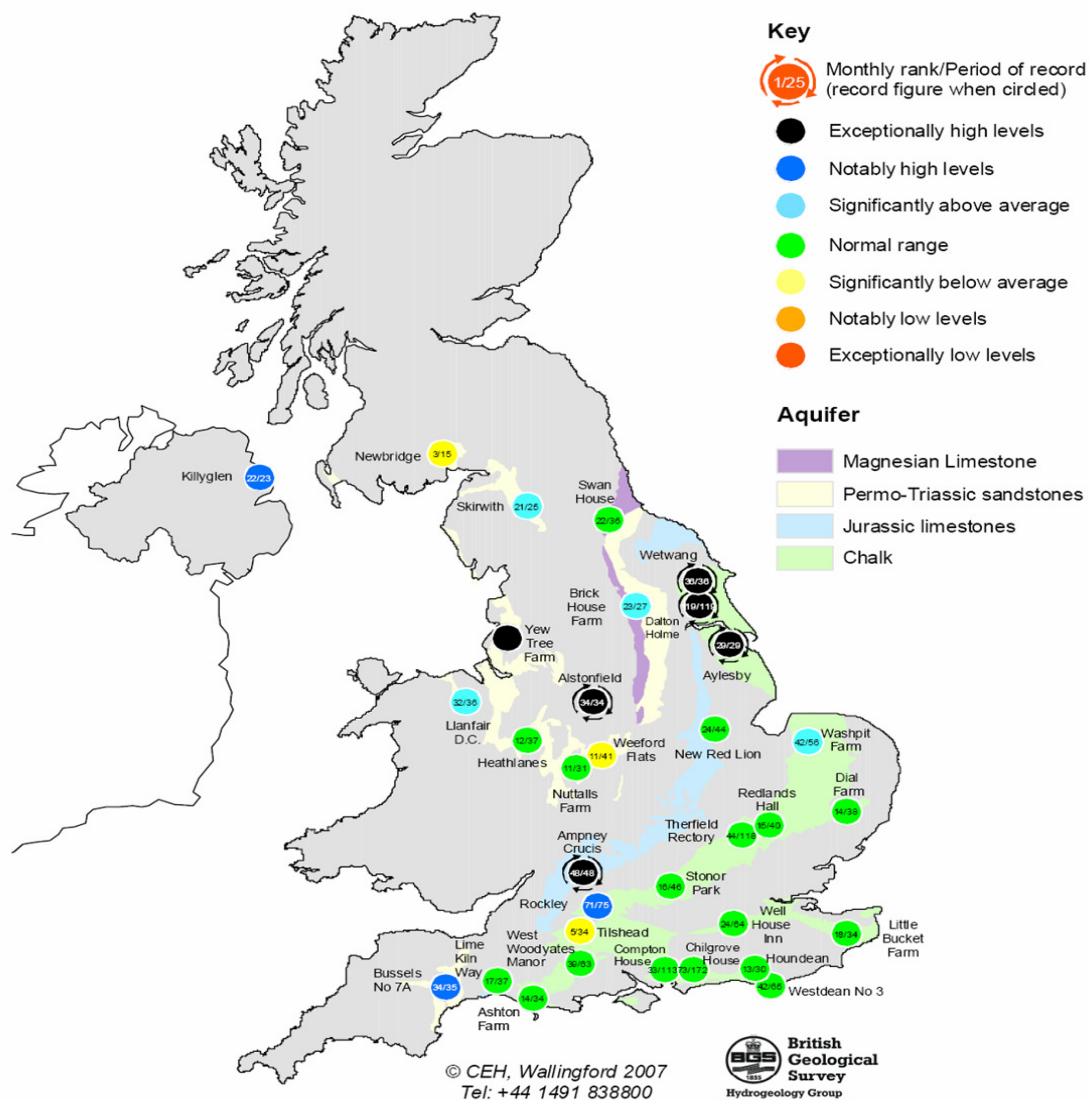


Figure 7 MORECS soil moisture anomaly at the end of September 2007

Groundwater levels - July 2007



The rankings are based on a comparison between the average level in the featured month (but often only single readings are available) and the average level in each corresponding month on record. They need to be interpreted with caution especially when groundwater levels are changing rapidly or when comparing wells with very different periods of record. Rankings may be omitted where they are considered misleading.

Notes: i. The outcrop areas are coloured according to British Geological Survey conventions.
ii. Yew Tree Farm levels are now received quarterly.

Figure 8 July 2007 groundwater levels

Groundwater levels - September 2007

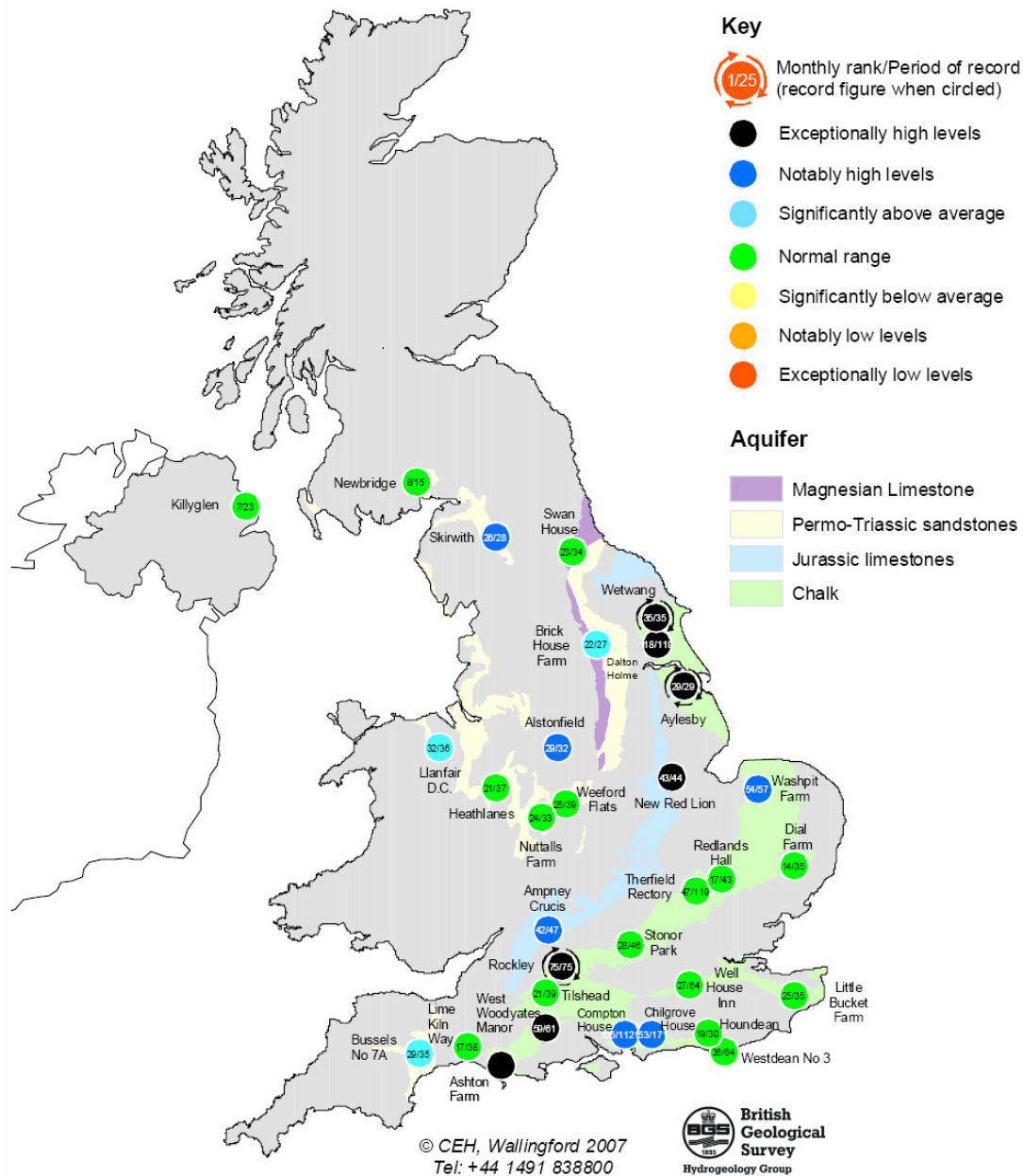


Figure 9 September 2007 groundwater levels

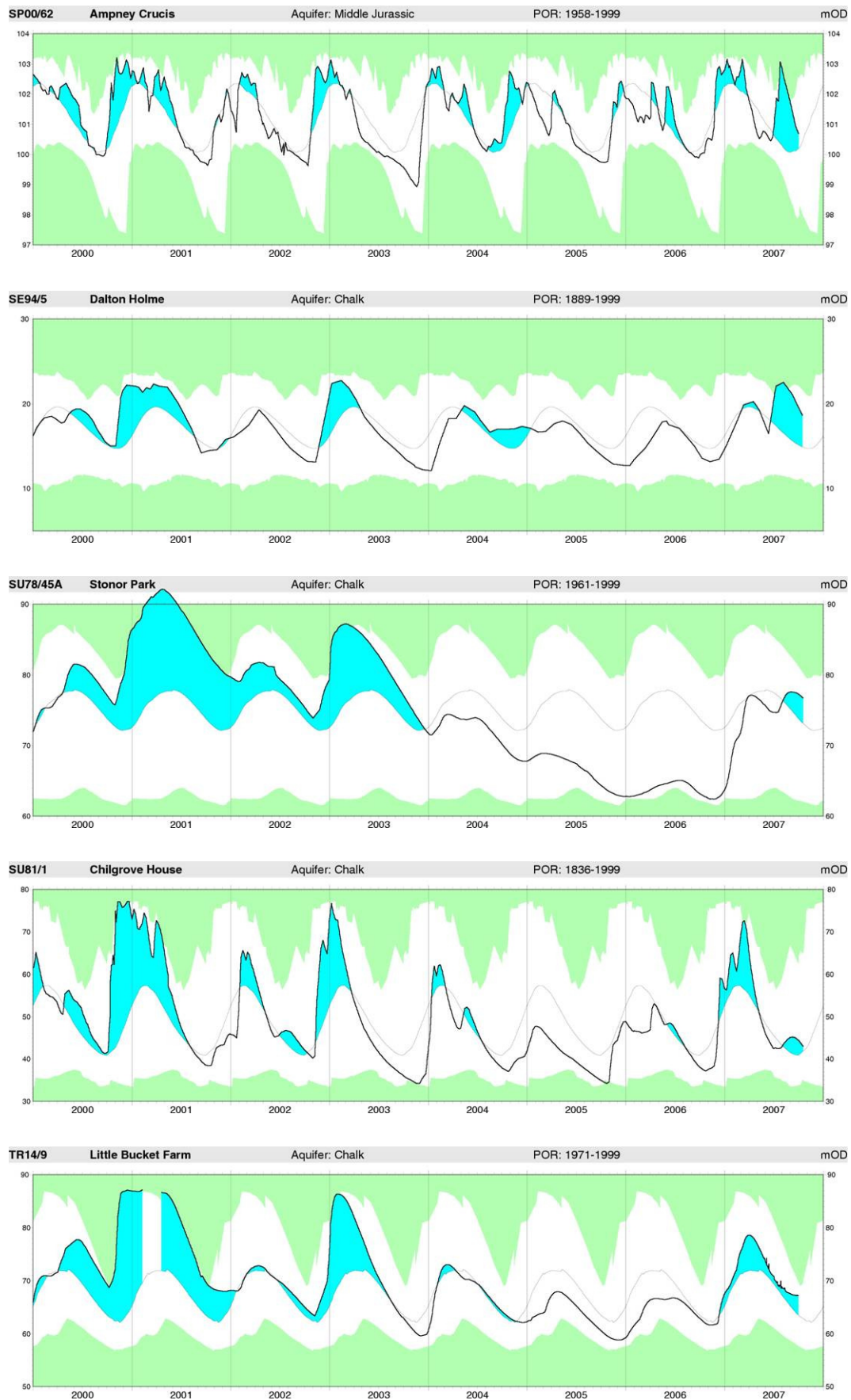


Figure 10 Groundwater levels for a number of index wells and boreholes in England

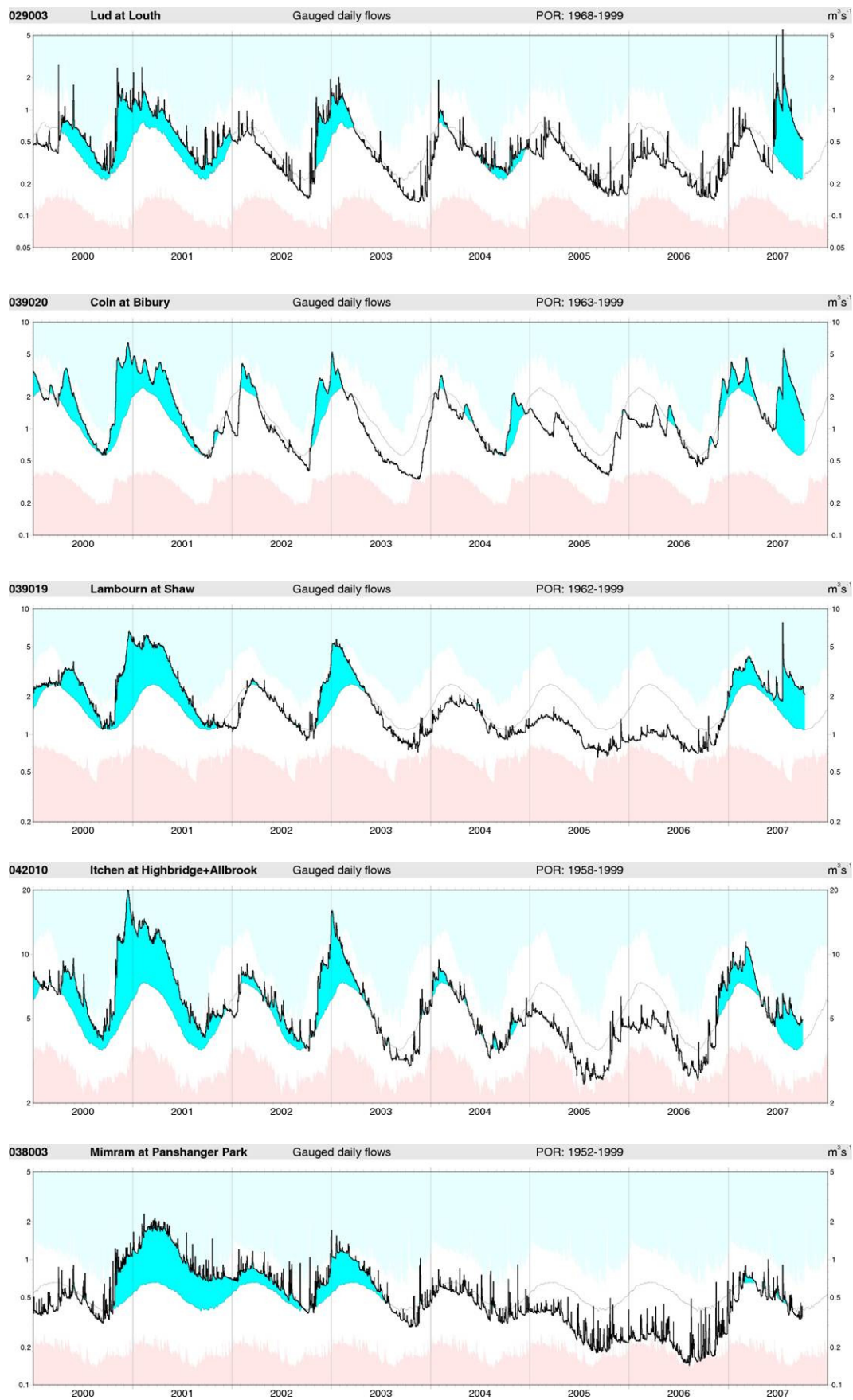


Figure 11 Daily flow hydrographs for a number of index rivers in England

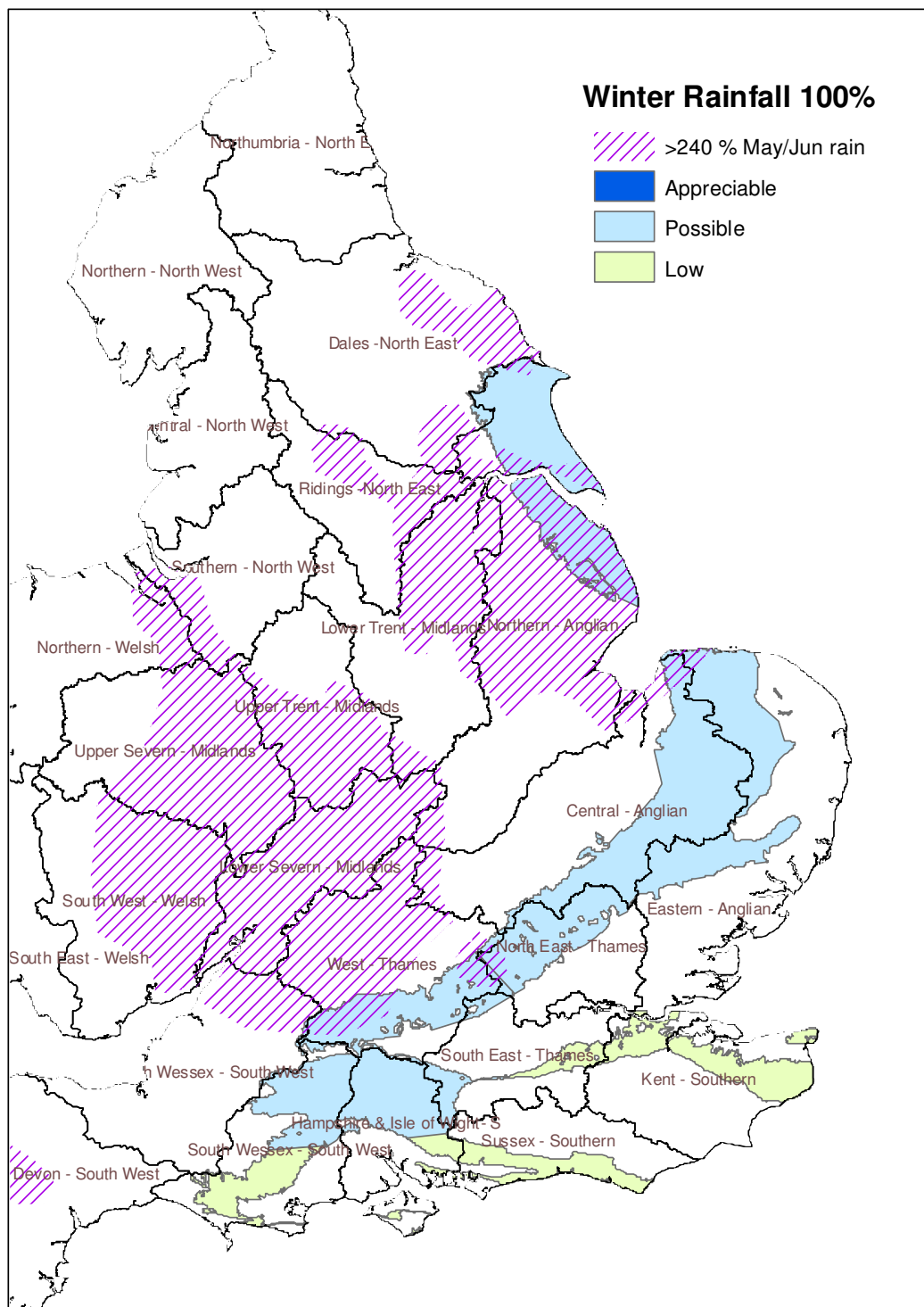


Figure 12 Areas of the Chalk outcrop at risk from groundwater flooding assuming 100% average winter rainfall

Autumn 2006 was the warmest on record for the UK and also wetter than the 1971-2000 average. Autumn 2007 so far has seen a predominance of settled weather over the UK – consistent with the outcomes stated as most likely in our initial forecast and in last month's update. In most regions, the settled weather has resulted in drier-than-average conditions and mean temperatures above 1971-2000 averages, as shown by provisional data.

Our forecasting methods continue to indicate that high pressure systems will tend to influence the British Isles during much of November. This suggests the following prospects, where averages refer to the 1971-2000 reference period.

- Mean temperature is more likely to be near, or above average, than below average
- Rainfall is more likely to be near, or below average, than above average
- Predominantly settled weather is likely, with an enhanced risk of frost and fog
- An increased risk of unsettled weather towards the end of November

Box 1 Met Office forecast for the November 2007